

BNL Proposal to Conduct Detector research and
development for a Future U.S. Neutrino Physics
Program Submitted to the U.S. Department of Energy
Office of High Energy Physics by Brookhaven National
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List of authors

Some figures in this document should be viewed in color.

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1 Executive Summary

This is a proposal submitted by Brookhaven National Laboratory (BNL), together with university partners having compatible research goals, to the U.S. Department of Energy (DOE), Office of High Energy Physics (OHEP), to conduct Detector R&D focused on the improvement of detector technologies and capabilities to support a more effective pursuit of future programs of neutrino research, especially in the neutrino oscillations sector where the scope of a definitive physics program can already be foreseen. Our proposals emphasize the R&D needed to optimize the design of a megaton-scale detector to be jointly used by the next-generation long baseline neutrino oscillations and proton decay experiments. These experiments are planned to share a large common detector located in the future Deep Underground Science and Technology Laboratory (DUSEL) now being developed by the National Science Foundation. This combined-use detector concept was noted as a high priority program objective in the "Theme 2: Dark Matter, Neutrinos, and Proton Decay" section of the February 2004 Office of Science and Technology Policy (OSTP) report, "The Physics of the Universe"[1]. The Detector R&D work proposed here will contribute centrally to the effectiveness of this important future national research direction.

Although we identify the large DUSEL detector as a key focus of this proposal, we also propose R&D tasks for intermediate-term neutrino projects. Specifically, we note that better liquid scintillators could greatly benefit near-term reactor experiments as well as potentially contribute to a very large scintillator-based DUSEL detector. We outline a topical detector R&D program that is structured to evolve over a three-year period, indicating technical goals, requested OHEP support levels and staffing to meet the R&D objectives. The R&D tasks are described in the main text.

The proposed R&D work below is submitted by a collaboration of Laboratory and university research scientists that plan to pursue complementary goals for the improvement of detector techniques and technologies that can advance the capability of the next generation detectors for the neutrino physics and proton decay searches identified above.

Our 1st priority is the development of integrated event simulation and pattern recognition software to optimize the signal to background ratio in large neutrino detectors. We will use the new software to critically compare the capabilities of water Cerenkov, liquid Argon and liquid scintillation detectors. Our 2nd priority is the detailed understanding of these same detector materials for their practical use in large detectors. Our 3rd priority is the development of improved photosensors for the water Cerenkov and liquid scintillator detectors,

Project Name	BNLPriority	FY06 (\$M)	FY07 (\$M)	FY08 (\$M)	Total (\$M)
Simulations and reconstruction	1				
Liquid Argon Large Detector	2				
Liquid Scintillator Detector	2				
Photo-sensor	3				

Table 1: Table of BNL/University Neutrino Detector R&D

possibly combining imaging optics with pixellated photo-sensors.

In Table 1, we list the proposed Detector R&D projects in the priority order of the collaboration proposing to perform the R&D work. We would like an opportunity to discuss these ideas with you as a way of assuring that we are in good mutual communication on the proposed topics of Neutrino Detector R&D.

2 Introduction

We urge that a large underground detector with an active mass of greater than 100kT become a key shared physics research facility for the future U.S. particle, nuclear and astrophysics research programs. A recent U.S. Government policy document, "The Physics of the Universe"[1], considers the science and technology that would be provided by such a detector and concludes that it has high scientific value and is therefore, "Ready for Immediate Investment and Direction Known" (Page 5). To bring this policy position to practical application, a near-term program of research and development is needed to decide on the appropriate technologies, perform engineering design studies for an appropriate site for such a detector, and determine the cost and schedule for such a project. The recently announced DOE-OHEP Neutrino Physics R&D initiative is an appropriate venue for pursuing the required detector R&D objectives. The National Science Foundation is currently carrying out a process to identify an appropriate site for this program under its "Deep Underground Science and Engineering Laboratory" (DUSEL) initiative.

A sensitive large detector with appropriate characteristics will answer questions of fundamental importance, such as nucleon decay and matter-antimatter asymmetry amongst neutrinos. The detector will also serve as a facility for continuously observing natural sources of neutrinos and cosmic rays.

The detector must have mass in excess of 100kT to allow us significantly greater statistical reach to search for nucleon decay and collect enough neutrino interaction events from intense accelerator based neutrino beams to measure neutrino properties with greater precision. The detector needs to have low energy threshold ($\leq 5\text{MeV}$) and good energy resolution to detect supernova and solar neutrinos. It should have good pattern recognition and timing capability and particle identification to distinguish electrons from muons and pions. To exploit the full scientific potential of such a detector, it will have to be located deep underground to shield it from cosmic ray background. Currently, only three technologies meet most of these requirements and lead to affordable designs. These technologies are water Cerenkov, liquid-Argon time-projection, and liquid scintillator detectors.

The advantage of a water Cerenkov detector is that it is a proven technology that has been perfected over several decades. Liquid Argon time projection chambers potentially offer very detailed measurements of particle physics events with superb resolution and particle identification. A new liquid scintillation detector could have very low energy threshold and coincidence capability to observe rare events. Water Cerenkov detectors are in operation in

Japan (Super Kamiokande with a total mass of 50 kT) and in Canada (The SNO detector in Sudbury). The 3 kT ICARUS liquid Argon detector is in the process of approval and installation of the first 600 tons of detector is in progress in the Gran Sasso Laboratory in Italy. The largest liquid scintillator detector in operation today is Kamland in Japan.

A program of R&D to further develop these technologies and to make a well considered choice is especially appropriate at this time because of the intense new interest in the physics of neutrinos [2] and the National Science Foundation's DUSEL process noted above. A unique opportunity for science could come to fruition in the US combining a new deep laboratory, a large detector and intense neutrino beams from existing national accelerator laboratories.

2.1 Scientific scope

A large, 100 kT detector can address three broad physics research topics: 1) neutrino oscillations using an accelerator-produced very long baseline neutrino beam; 2) improved search for nucleon decay; 3) detection and study of neutrinos from natural sources such as the Sun, Earth's atmosphere and past or current supernova explosions.

A large (> 100 kT) detector can address three broad topics:

- Neutrino oscillations with an accelerator produced long baseline beam.
- Nucleon decay.
- Detection and study of neutrinos from natural sources such as the Sun, the atmosphere, past or current supernova explosions.

2.2 Detector technologies

Plain description of how the three technologies work. This has to be targeted for a scientifically literate audience, but not expert audience.

Water Cherenkov

Liquid Argon

Liquid Scintillator

3 Research and Development Topics

Make a broad list of items that need immediate attention for all three. Make three tables and add up the numbers. Set a goal of getting to a proposal in 1-2 years.

3.1 Simulations and software

-Brett.

Neutrino Production Simulation for Design and Physics Reach Studies

A detailed and flexible simulation of the BNL VLBL neutrino flux is crucial for optimizing the beam line design and understanding the physics reach of the experiment. It is necessary to implement this in a way that it remains relevant for the foreseeable future. To allow fast implementation and secure support for the future it will be implemented with the GEANT4 simulation framework. It is estimated that 1 FTE-year is required for initial development and a part time of 1 FTE-month thereafter. This is best with a mixture of existing experienced group members with a new postdoc and a very talented graduate student.

Simulation of the UNO Detector and Realistic Reconstruction Software

Proving that the BNL VLBL concept is viable, and indeed the best next generation neutrino oscillation experiment is currently hindered by the lack of accurate simulation and knowledge of realistic reconstruction efficiencies and background rejections. To remedy this more effort is needed in finishing existing UNO MC and developing a reconstruction software suite. This work has begun but must accelerate. This is of course an effort that will continue into the construction and running phase but initial studies can be made after 2 FTE-years. This can consist of bringing visitors to BNL to work in close communication with experts here and at and/or hiring a postdoc.

It is possible for individuals to contribute to both areas.

Kahn

Proposal for the Development of a Reconstruction and Analysis Package for Evaluation of the Backgrounds in a Water Cherenkov Detector

1. Short Description of R&D:

Reconstruction and Analysis Package: - In order to evaluate the performance of a water Cherenkov detector we need a reconstruction and analysis program to take photo-tube hits

produced in a simulation program such as Geant to what can be called reconstructed events. There are political reasons why we can't use the Super-K codes that do that. There is the UNO package which is somewhat complicated to use and carries a high level of computer software sophistication that is not necessary for the kind of studies that we want to do. We need to develop a reconstruction/analysis "toy model" package that can be used as a tool for testing algorithms for reconstruction and background suppression. It needs to be sophisticated enough for our studies, but it need not contain the overhead for experimental data (yet).

Background Studies: - We need to understand backgrounds from either NC single pizero or multiple pizero channels. This study needs to be done independently of the Stony Brook study and we need to full flexibility to vary the parameters and cuts to reduce backgrounds and we need to be able to present and publish the background study results. These kinds of studies would rely on the existence the a reconstruction/analysis package.

Implementation of BNL VLBL experiment in GLoBES

The Global Long Baseline Experiment Simulator (GLoBES)[3] is a software system that performs a fast simulation for LBL neutrino experiments. This allows for an easy comparison between and combination among various experiments. This tool has become very popular amongst theorists to test the sensitivity of future experiments to neutrino oscillations and specific models for New Physics. It is essential for BNL that the very long baseline concept gets as much exposure as possible. Providing the necessary inputs to GLoBES will help greatly.

The most crucial inputs for GLoBES are the neutrino fluxes, the energy resolutions and reconstruction efficiencies. So far, only a crude version of the VLBL experiment input files exists. The current flux files need to be validated against the original fluxes. The resolutions and efficiencies are derived from simplified Monte Carlo predictions. One of the UNO collaborators at Stony Brook has recently made great progress with a more detailed study to reduce the background levels. They certainly need to be incorporated in the GLoBES input files for the VLBL. There is also an elaborate effort going on to have a full Monte Carlo simulation of a 0.5 Mton water Cerenkov detector. The resulting numbers, as well as any other future change to the experimental setup and predictions, should be incorporated in the input files.

The required time for this project is 3 months fte during the first year for providing the proper GLoBES input files. Thereafter, it requires about 1 month fte per year thereafter for maintaining those files.

3.2 Liquid Argon Large Detector

Proposal for Liquid Argon Neutrino R&D Plan

1. Short Description of R&D:

Evaluate the feasibility of a 100 kiloton liquid argon detector as a choice for the Brookhaven Very Long Baseline Experiment. Some of the R&D issues would include: - Can 100 kT Liquid argon using all (or most) charged current channels produce the same physics reach as 500 kT water cherenkov detector using only the quasi-elastic channel. - Establish efficiencies for nue and pizero background rejection. - Establish whether such a detector could be placed at the surface (or near the surface) for the neutrino physics program (ignoring proton decay). Can we live with the cosmic ray background. - Establish a realistic cost estimate for a 100 kT detector based on current or reasonably achievable (conservative) technology. - What would the physics potential be if such a detector were situated in Minnesota to be shared by two neutrino beams from different laboratories.

As there is some concern that BNL does not have experience with liquid argon, collaboration with the group at Fermilab interested in liquid argon would be necessary.

2. How long would it take? 3 years

3. Who is the proponent? S. Kahn, H. Kirk, J. Gallardo

4. How many people are involved?

5. University and other participation? UCLA, Princeton ? (not confirmed).

6. How much money over 3 years? 50 K\$/year for engineering. 10 K\$/year for expenses for visitors, workshops and travel

3.3 Liquid Scintillator Large Detector

Research and development is needed for new liquid scintillator materials for two important reasons. It is clear that a reactor based experiment to determine the unknown parameter θ_{13} will be an important part of the next stage of neutrino oscillations research. To optimize the capabilities of the associated experimental detectors, R&D is needed for new liquid scintillator (LS) materials. Such new scintillators could also have applications for very large neutrino detectors at a later stage neutrino research. The R&D proposed here is centered in the BNL Chemistry Department's Solar-Neutrino/Nuclear-Chemistry Group. There are two main efforts going on in the group: the first, development of Gd-loaded liquid

scintillators, has made a lot of progress during the past 1-2 years; the second, application of the new scintillators to very large experimental detectors, is an extension of these efforts for the longer term.

R&D Task I - Gd-loaded Liquid Scintillators (Gd-LS) for new Reactor-Based θ_{13} Experiments:

The Solar-Neutrino/Nuclear-Chemistry Group ("the Nuclear-Chemistry Group") is a participant in two existing U.S.-based θ_{13} R&D projects: (a) the Braidwood collaboration (co-spokesmen Mike Shaevitz of Columbia U. and Ed Blucher of U. Chicago) that would be done at the Braidwood reactor in Illinois, which is run by the Exelon Co.; and (b) the Daya Bay collaboration (co-spokesmen Stuart Freedman of UC-Berkeley and LBNL and Yifang Wang of IHEP, Beijing) that would be done at the Daya Bay nuclear-reactor power-station near Shenzhen, China, an hour's drive north of Hong Kong.

Both collaborations (with the participation of the Nuclear-Chemistry Group) have been active for the last 1-2 years (see Appendix to this section). In fact, in the fall of 2004, the Braidwood collaboration submitted identical proposals for R&D funding to NSF and DOE; at that time, the Daya Bay collaboration made a brief R&D submission to NSF and is currently preparing a lengthy document that it will send to both NSF and DOE. The purpose of these proposals is to obtain funding on the order of \$1 M each for continued R&D and for detailed engineering studies in preparation for full-scale construction proposals that will be submitted in 2006.

Both collaborations (Shaevitz for Braidwood and Freedman for Daya Bay) made invited presentations to the Neutrino Scientific Advisory Group (NuSAG) in early June 2005. It is likely that funding decisions will be made about these proposals before the end of calendar 2005.

The role of the Nuclear-Chemistry Group is the same in both collaborations: to develop and perfect the gadolinium-loaded organic liquid scintillator (with Gd concentrations 0.1-0.2% critical functional element of the antineutrino detector. Properties that have been identified by the Group as key indicators of excellent LS performance are: long-term chemical stability (for a period of at least 3 years); high light output; and high optical transparency (optical attenuation length $A. L. \approx 10$ meters). Other important issues that the Group is beginning to study include the chemical compatibility of the Gd-LS with the detector vessel (which will likely be made of a plastic such as acrylic or nylon) plus the assay, removal and control of the chemical and naturally radioactive impurities in the Gd-LS. Some notable achievements that the Group has obtained to date, mainly with pseudocumene (PC) as the

organic LS medium (and more recently with a mixture of PC and dodecane), are: (1) excellent optical transparencies, with A. L. 15 meters; (2) light output 95% of pure PC; and (3) perhaps most importantly, stability of these crucial properties over the period to date of >200 days.

The proposals that were made to the funding agencies by the two collaborations included some requested funding for the BNL Nuclear-Chemistry Group for chemical supplies and equipment, \$40 K. However, there were no specific requests in these proposals by any of the participating institutions for additional scientists to do the R&D. The BNL Group is small at present, with two staff members, one postdoc, and one part-time chemical consultant. To perform all of the designated tasks that need to be done in the next year or so, including preparing hundreds of liters of Gd-LS for collaboration colleagues to test in prototype antineutrino detector modules, the Group will have to hire at least two more postdocs or junior scientists for a minimum of two years. To do so, Hahn has already requested BNL LDRD funding at \$250 K per year, to begin in FY 2006. This request is pending. If one or both θ_{13} construction projects receive U.S. funding, the experiments will utilize four or more identical antineutrino detectors, each one containing 65 tons or more of Gd-LS. Construction would begin in 2007, with data taking projected to begin in 2009 or 2010. To meet this ambitious schedule, the BNL Nuclear-Chemistry Group will certainly have to grow to at least double its current size in order to do and/or coordinate the required industrial-scale production. And if the production is to be done at BNL, new chemical facilities will have to be built here. [Is there an argument that this seeming industrial procurement needs to be done at BNL?]

A special note: the BNL Solar-Neutrino/Nuclear-Chemistry Group has traditionally received research funding from DOE's Office of Nuclear Physics (ONP). However, there has been some speculation that, instead of following the "KamLAND" model where both ONP and Office of High Energy Physics (OHEP) shared in providing the U.S. part of the funding, a new model may be developed where ONP will focus on funding new double beta-decay experiments and OHEP will focus on funding the reactor θ_{13} experiments. In that case, it will be especially important that the BNL group's work to be included in the present BNL Neutrino Proposal proposal to OHEP.

The projected LS R&D budgets for the next three years for R&D Task-I comprise:

Task-I R&D Budgets by Fiscal Year	Budget Item	FY 2006 (\$K)	FY 2007 (\$K)	FY 2008 (\$K)	Sum (\$K)
Personnel	300	330	500	1130	
Eq. and Chemicals	100	150	?		

Totals 400 480 ?

a Personnel needed: FY 2006 and 2007, 3 postdocs; FY 2008, 2 staff physicists + 3 postdocs

R&D Task II - Application of LS to Very Large Neutrino Detectors

Some new concepts are being developed for using LS as the detection medium instead of water-Cherenkov in huge neutrino detectors on the scale ~ 100 ktons. See, for example, the accompanying proposal by R. S. Raghavan of Virginia Tech University [how will Raghavan's proposal be referenced?].

The BNL Nuclear Chemistry Group is well placed to contribute to such projects. This group has performed R&D with liquid scintillators (LS) for the past four years, first in collaboration with Raghavan in connection with the proposed LENS low-energy solar neutrino detector and, more recently, with the θ_{13} experiments. We have developed extensive expertise in a variety of organic-chemical synthesis and purification procedures for preparing the LS, and we continue to seek improvements in our methods. There are very few groups worldwide that have this expertise.

A very important question in all of this R&D concerns the long-term stability of the LS, since several proposed new experiments may have lifetimes on the order of several years. It is conceivable that, in the case of an organic LS that is not loaded with a metal (as is being used in Borexino or in KamLAND), it may be possible to chemically purify the LS after the experiment has begun. However, even in that case, the purification steps will be difficult because the organic LS will contain more than one component. For example, the added fluors will behave differently during chemical purification than will the liquid components of the LS. In the case of metal-loaded LS, chemical purification after the chemical synthesis has been completed will be close to impossible since most purification steps will remove the metal that had been intentionally added during the synthesis, thereby changing the properties of the LS. Furthermore, any such purification steps will be difficult to implement on the greater than kiloton scales that are being considered for the next-generation experiments.

In view of these potential problems, the BNL Nuclear Chemistry Group has paid close attention to developing purification methods that can be applied before and during the chemical preparation of the LS, e.g., to remove chemical and radioactive impurities from the LS. We also continue to develop techniques to monitor the long-term stability of our LS formulations, in what we refer to as a QC program. In particular, we have purchased and/or developed equipment to measure what we consider to be two of the key characteristics of the LS, its light output and its attenuation length (AL). For example, we have developed new systems to measure the AL of liquids: a 1-meter laser-based system (at a wavelength

of 442 nm) and a new 2-meter system that we are currently building, that will use LED's to provide light at several different wavelengths. We are doing this work in collaboration with Milind Diwan and members of the Neutrino Group in the BNL Physics Department.

BNL Nuclear Chemistry Group is also considering improving its capabilities for doing low-level nuclear counting, to measure the signal decay time and the photon production efficiency per unit incident energy, and to monitor radioactive contaminants in the LS and in materials that are being considered as candidate construction materials for new neutrino detectors. Concomitant issues concern the chemical compatibility of the LS with the proposed materials that will comprise the detector vessel; e.g., it is well known that many organic liquids will attack various plastics, and there are standardized tests that we will use, that have been developed to test for chemical incompatibilities.

In essence, the R&D for such long-term large-scale physics applications at BNL of LS for new neutrino detectors will be in addition to our dedicated work on θ_{13} experiments. We propose to expand the Nuclear Chemistry Group on the basis of our existing, unique expertise to become a well-equipped BNL center with full capability for the preparation, purification, and systematic monitoring and analysis of new LS materials, which may well be feasible for future double-beta nuclear decay (such as the proposed SNO+ experiment at SNOLab) and long-baseline neutrino experiments.

The projected R&D budgets for the next three years for R&D Task-II comprise:

Task-II R&D Budgets by Fiscal Year	Budget Item	FY 2006 (\$K)	FY 2007 (\$K)	FY 2008 (\$K)	Sum (\$K)
	Personnel	200	220		

500	1130	Eqp. And Chemicals	100	100	?
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Totals	400	150	?
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a Personnel needed: FY 2006 and 2007, 2 postdocs; FY 2008, 1 staff physicists + 2 postdocs

3.4 Photo sensor R&D

Hyper Scintillation Detector (HSD)

Hyper Scintillation Detector A working group has been constituted to study the design of a hyper scintillation detector (HSD) with 50-100 kT of liquid scintillator. The objectives of the detector cut across a wide swath of frontier questions in basic science that can be answered only by such an unprecedented detector that can in principle, observe both low

and high energy events with energies from 100 GeV to 100 keV. No other present or future detector has a comparable scope in the energy and the motivating science. The detector can be sited in any one of the proposed DUSEL sites, in particular, in the Kimballton limestone mine, about 30 min. from VT. This site has already large (larger than Gran Sasso) caverns (typically 15x15x200m) at 1800 mwe depth. Deeper sites are envisioned in the Kimballton-DUSEL program. The proximity to VT provides a strong base for academic interactions and technical infrastructure for rapid development of large scale collaborative experiments.

Scientific Scope: * Elementary particles: 1. a deep search for the decay of the proton 2. fundamental questions in neutrino physics such as: * search for CP violation in the neutrino sector, * deep search for the 3-neutrino mixing parameter θ_{13} * the hierarchy of the neutrino mass matrix using high energy neutrinos produced on a long baseline from Kimballton either at the Brookhaven National laboratory or at Fermilab.

* Geophysical structure and evolution of the Earth: 1. the structure * of the earth's crust and mantle via global observation of * anti-neutrinos emitted by the distributed radioactivity in these * regions Note that this detector also offers the parasitic * opportunity of a yes/no test of the idea of a fission reactor at the * center of the earth by a search for the "smoking gun" for the geo * reactor-antineutrinos.

* Astrophysics of exploding stars (Super Novae): by observation of * antineutrinos emitted both in the precursor and explosion phases

* High Red Shift Cosmology : via detection and spectroscopy of the * relic antineutrino background from past supernovae

Why Scintillation Technology: A common basis for all the above topics is spectroscopy of antineutrinos via tagged detection –a strong point of scintillation technology. It is this specificity that allows the applications to very low energies without being overwhelmed by background. The ability to see particles below the Cerenkov threshold provides the other major advantage. Because of these facilities, the liquid scintillation technology offers a competitive approach relative to Cerenkov and Liquid Argon technologies for high energy applications and extends the scientific scope well beyond to low energy problems of geo- and cosmo- physics cited above. Further, the technique could lead to a significantly smaller detector compared to the above approaches for comparable physics goals. The extended scope with a smaller detector summarize the motivating factors for HSD. We are convinced that the HSD approach, presented at the recent BNL-UCLA Large Detector Workshop, is an integral component of any development program for very massive detectors of the future.

Search and Discovery Potential: The above topics offer an attractive mix of search and discovery. Proton decay is an open ended problem, i.e. it may or may not be observable as with any of the three technological approaches. In a project of this magnitude which requires major resources, it is imperative to build in "safe" discoveries along with open ended search programs. The potential observation of geophysical antineutrinos and the first global elucidation of the internal structure of the earth, and of supernova relic neutrinos that probe the high redshift universe are guaranteed discoveries of fundamental impact on the science of the 21st century. The basic energy budget of the earth addressed by geo-neutrino spectroscopy is of particular relevance to the basic mandate of the Department of Energy.

Working Group: This project is proposed by a group of theoretical and experimental scientists who have contributed to the science addressed by proposed HSD. In particular the experimentalists are leading scientists that have made pioneering contributions to the conception, design and operation of large-scale high and low energy detectors (BOREXINO, IMB, KamLAND, MACRO and Superkamiokande) that employ both water Cerenkov and liquid scintillation methods. A generic detector of HSD type has been under consideration for some time by individual members of the group from various points of interest: A preliminary list of the proponents of HSD includes:

John Learned and S. Pakvasa (U Hawaii) Robert Svoboda (LSU) Franz v. Feilitzsch and Lothar Oberauer (Tech. U. Munich), Kate Scholberg (Duke U), Y. Kamyshev (U. Tennessee) Bruce Vogelaar, Mark Pitt, Tatsu Takeuchi, Lay Nam Chang and R. S. Raghavan (VT)

Proposed Work and Budget: Liquid scintillation technology itself is a mature approach based on modern massive detectors such as KamLAND and BOREXINO. The specific applications to high energy physics problems as well as a optimization for combined high and low energy objectives is new. We foresee three major directions that are urgent and most fruitful for developing a detector strategy. 1. Simulation work for application of scintillations to proton decay 2. Simulations of long base-line oscillations of antineutrinos. 3. Development of suitable scintillation detector media (possibly combined with Cerenkov capability) 4. Development of new detector designs of very massive detectors.

We foresee investing in 4 post doctoral scientists to examine these 4 topics. The institutions of the working group have strong infrastructures and programs on existing large detectors so that start up work would be relatively rapid. Thus hardware funds can be relatively a smaller fraction of the program. A very preliminary budget for 2 years is thus:

Post-doctoral personnel: $4 \times 200 = 800K$ Hardware, Travel etc 100 K Total 900 K

3.5 Co-ordination with the neutrino factory and superbeam scoping study

4 Conclusion

Plans for a detector should be ready by the time a DUSEL is chosen.

Total budget and schedule for the R&D request

Text of the neutrino factory and superbeam scoping study

List of Collaborators

Reactor Neutrino Experiment Collaborations

The Daya Bay Neutrino Collaboration X. Guo, N. Wang, R. Wang, Y. Wang, Beijing Normal University, Beijing A. Garnov, R. Hahn, C. Musikas, M. Yeh, Brookhaven National Laboratory, Upton R.D. McKeown, C. Mauger, C. Jillings California Institute of Technology, Pasadena L. Hou, B. Xing, Z. Zhou, China Institute of Atomic Energy, Beijing C. Chung, W. Ngai, A. Tang, The Chinese University of Hong Kong J. Cao, H. Chen, C. Jiang, J. Li, Y. Lu, Y. Ma, X. Meng, Y. Wang, Z. Wang, C. Yang, J. Zhang, Z. Zhang, Institute of High Energy Physics, Beijing Y. Wu, J. Yang, Institute of Theoretical Physics, Beijing B.L. Young, K. Whisnant, Iowa State University, Ames B.E. Berger, P. Decowski, S.J. Freedman, B.K. Fujikawa, K.M. Heeger, L. Hsu, R.W. Kadel, K.B. Luk, Lawrence Berkeley National Laboratory/University California-Berkeley X. Li, Y. Xu, Nankai University, Tianjin H. Niu, L. Niu, Shenzhen University, Shenzhen Q. Su, Tsinghua University, Beijing K.S. Cheng, J.K.C. Leung, C.S.J. Pun, University of Hong Kong H. Liang, G. Jin, J. Wang, Q. Wang, X. Yu, Y. Zhou, University of Science and Technology of China, Hefei X. Ji, University of Maryland, College Park V.I. Aleshin, Yu.V. Gaponov, V.I. Kopeikin, V.P. Martemyanov, L.A. Mikaelyan, V.G. Tarasenko, V.N. Vyrolov, Kurchatov Institute, Moscow Yu. Gornushkin, I. Nemchenok, A. Olchevski, E. Yakushev, Joint Institutes of Nuclear Research, Dubna At present the Daya Bay Collaboration consists of 70 scientists from China, Russia, and the U.S.

The Braidwood Neutrino Collaboration Argonne National Laboratory: M. Goodman, V. Guarino, J. Reichenbacher, D. Reyna Brookhaven National Laboratory: A. Garnov,

R. Hahn, C. Musikas, M. Yeh The University of Chicago: E. Abouzaid, K. Anderson, E. Blucher¹, M. Hurwitz, A. Kaboth, D. McKeen, J. Pilcher, E. Pod, J. Seger, M. Worcester
 Columbia University: J. Conrad, Z. Djurcic, J. Link, J. Ma, K. McConnel, M. Shaevitz¹,
 G. Zeller Fermi National Accelerator Laboratory: L. Bartosek, D. Finley, H. Jostlein, C. Laughton, R. Stefanski
 Kansas State University: T. Bolton, J. Foster, G. Horton-Smith, N. Stanton, D. Thompson
 University of Michigan: M. Longo, B. Roe Massachusetts Institute of Technology: R. Cowan, P. Fisher, M. Miller, L. Osborne, G. Sciolla, S. Sekula, F. Taylor, T. Walker, R. Yamamoto
 Oxford University: G. Barr, S. Biller, N. Jelley, G. Orebi-Gann, S. Peeters, N. Tagg, A. Weber
 University of Pittsburgh: B. Dhar, S. Dytman, N. Madison, D. Naples, V. Paolone, C. Pankow
 Saint Mary's University: P. Nienaber University of Sussex: E. Falk Harris University of Texas at Austin: A. Anthony, M. Huang, J. Klein, K. Kucera, S. Seibert, C. Tunnell
 University of Washington: J. Formaggio 14 Institutions; 70 Collaborators

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